ENVIRONMENTAL AFFAIRS

PCS Mining

A subsidiary of the Potash Corporation of Saskatchewan

USE OF INJECTION WELLS AT PCS MINING FOR DISPOSING OF WASTE POTASH BRINE

FINAL REPORT

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Executive Summary

Potash mines in Saskatchewan are required to use injection wells to dispose of excess brine. Wells in the central part of the Province inject into the sandstones of the Winnipeg and Deadwood Formations. Since these formations are thin in the southeastern part of the province, the wells inject into the carbonates of the Interlake Formation.

Injection wells consist of an outer casing cemented from the bottom of the casing to the surface, and an inner casing or injection tube which is inserted into the outer casing. The area between the two pipes is sealed with a packer and is filled with pressurized, corrosion inhibiting fluid.

Some wells have the outer casing extended to the bottom of the hole and, after it is perforated, injection takes place through the outer casing. In other wells, the outer casing stops at the beginning of the disposal zone and the inner tube which is perforated, continues into the injection zone and is the instrument of injection. In still other designs, both the outer casing and inner tube stop at the beginning of the disposal zone and injection takes place in the open hole.

Wells have generally been constructed with few difficulties.

In the Deadwood-Winnipeg Formations, wells are 5 000 to 6 000 feet deep, and absorb brine at the rate of 64-138 $ft.^3$/min. at pressures between 350 and 950 psi. The Interlake Formation wells are shallower at about 4 000 feet deep and absorb brine at the rate of 32-85 $ft.^3$/min. at pressures around 400 psi. Formation pressure testing indicates that both formations are dissipating the brine.

The most common problems with injection wells are: firstly, packer failure; secondly, leaks developing in the injection tubes; and thirdly, gradual decreases of assimilative capacity. Technology exists for readily replacing the packer and injection tubes and re-perforating the disposal zones. Wells appear to become obstructed with salt if they are shut down for prolonged periods or fed at a low rate. Salt obstructed wells can generally be cleaned out.

Acidizing has been used to improve well performance, and may be an effective remedial measure for wells injecting into carbonate formations. However, it is doubtful if this one technique is effective for rehabilitating wells injecting into the sandstones of the Winnipeg and Deadwood Formations.

Wells may suffer less obstructions if they are allowed to drain completely upon being shut down. The practice of allowing wells to drain back to the sump may generate upward pressures which will raise the packer or bring debris into the well.

Wells might be more effective if more consideration was given to the site geology when locating a new well. Additional geological data, which could easily be collected when drilling a well, would facilitate designing other wells in the area.

The most cost effective well design appears to be the "open hole" type whereby both the outer casing and injection tubes stop at the top of the injection zone. These wells are less expensive to construct and rehabilitate.

In the short term, the use of injection wells in Saskatchewan for disposing of excess potash brine appears to be a cost effective solution for minimizing environmental contamination. Since the location and timing of discharge from the injection formations has not been clearly established, the long term environment impact of this waste disposal practice is still undetermined. However, significant environmental impact is considered unlikely, even in the long term, because the chemical composition of the natural fluid in the injection zone is similar to that of potash brine. Also there is a large area available to assimilate brine. The discharge location appears to be hundreds of miles from the injection site. The rate and movement of brine through the formations appears to be slow and the fluid in the disposal formation does not appear to be connected with any shallower or non-saline water.

SOMMAIRE DE L'EXECUTIF

On demande aux mines de potasse de la Saskatchewan de se débarrasser de leur surplus d'eaux salées dans des puits à injection. Dans le centre de la province les puits injectent dans les grès des Formations Winnipeg-Deadwood. Ces formations ne sont pas épaisses dan le sud-est de la province, et dans cette partie les puits injectent dans les carbonates de la Formation Interlake.

Les puits d'injection sont faits d'une paroil extérieure cimentée depuis le fond du cuvelage jusqu'au sommet et d'une paroi intérieure ou tuyau d'injection qui s'insère dans le revêtement exterieur. L'espace compris entre les deux parois est scellé par une garniture d'étanchéité et rempli d'un liquide pressurisé qui empêche la corrosion.

Dans certains puits la paroi extérieure va jusqu'au fond du trou et l'injection se fait par cette paroi extérieure, une fois qu'elle a été perforée. Dans d'autres puits la paroi extérieure s'arrête là où commence la zone de déversement, et c'est la paroi interieure qui, une fois perforée, continue jusqu'à la zone de déversement et sert à l'injection. Il existe encore d'autres modèles de puits dans lesquels la paroi extérieure et le tuyau intérieur s'arrêtent là où commence la zone de déversement, et l'injection se fait alors par l'ouverture du trou.

En général, la construction des puits n'a présenté que peu de difficultés.

Dans les Formations Deadwood-Winnipeg les puits ont de 5000 à 6000 pieds de profondeur, et ils absorbent les eaux salées au rythme de 64 à 138 pieds cubes à la minute, à des pressions allant de 350 à 950 livres par pouce carré. Dans la Formation Interlake, les puits, moins profonds, ont environ 4000 pieds de profondeur, et ils absorbent les eaux salées au rythme de 32 à 85 pieds cubes à la minute, à des pressions variant autour

de 400 livres par ouce carré. L'étude la pression dans les formations indique que les deux formations favorisent la dissémination des eaux salées.

Les problèmes les plus communs que l'on recontre dans les puits d'injection sont les suivants: en premier lieu la garniture d'étanchéité ne remplit pas ses fonctions; deuxièmement il y a des fuites dans les tuyaux d'injection, et troisièmement la capacité d'assimilation diminue graduellement. Grâce à des procédés techniques on peut remplacer rapidement la garniture d'étanchéité et les tuyaux d'injection, et perforer de nouveau les zones de déversement. Il arrive que le sel bouche les puits qui ne sont pas utilisés pendant de longues périodes ou qui sont alimentés à un régime lent. En général, on peut nettoyer les puits bouches par le sel.

On a utilisé l'acidification pour améliorer le rendement des puits; ce procédé peut donner de bons résultats pour la remise en état des puits qui injectent dans les formations de carbonates. On doute cependant de l'efficacité de cette méthode lorsqu'il s'agit de la remise en fonction des puits qui injectent dans les grès des Formations Winnipeg et Deadwood.

Il est possible que les puis se bouchent moins facilement si on leur donne le temps de se vider à la fermeture. La méthode qui consiste à permettre l'évacuation jusqu'au puisard peut donner naissance à des pressions ascendantes capables de soulever la garniture d'étanchéité ou d'apporter des débris dans le puits.

Les puits donneraient de meilleurs résultats si l'on faisait plus attention au site géologique lorsqu'on cherche un endroit où creuser le puits. L'addition de données géologiques, que l'on peut facilement obtenir lorsqu'on creuse un puits, faciliterait le forage d'autres puits dans la région.

Le type de puits qui semble être le plus avantageux du point de vue financier est "le puits à découvert", dans lequel la paroi exterieure et les tuyaux d'injection s'arrêtent là où commence la zone d'injection. Les puits de ce genre sont moins couteux à construire et à remettre en état.

Pour l'instant, l'emploi en Saskatchewan des puits d'injection pour se débarrasser du surplus des eaux salées de la potasse semble être la solution la plus efficace pour minimiser la contamination de l'environnement, et la plus avantageuse du point de vue financier. L'emplacement et la durée de l'écoulement provenant des formations qui reçoivent l'injection n'ont pas encore été définis de façon nette; de ce fait, les effets à long terme sur l'environnement de cette methode de débarras des déchets ne sont pas encore déterminés. De toutes façons, il est peu probable que les effets sur l'environnement soient importants, même sur une longue période de temps, et voici pourquoi: la composition chimique du liquide naturel présent dans la zone d'injection est semblable à celle des eaux salées de la potasse, l'espace, ne manque pas pour l'assimilation des eaux salées, l'endroit où se fait le déversement est situé à des centaines de milles du site d'injection, le débit et le deplacement des eaux salées dans les formations sont lents, semble-t-il, et il ne paraît pas y avoir de contact entre le liquide qui coule dans la formation où on fait le déversement et les eaux non salées ou les eaux qui coulent à une profondeur moindre.

USE OF INJECTION WELLS AT PCS MINING FOR DISPOSING OF WASTE POTASH BRINE

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INTRODUCTION

The potash industry in Saskatchewan uses brine extensively to extract potash (potassium chloride) from sylvinite ore (Figure 1). The ore is crushed and floated in brine, which is saturated in potassium chloride to prevent the potash from dissolving. Since loss of process brine involves loss of product, most of the process brine is recycled but losses occur from various points within the circuit (Figure 2). These losses which can approach 600 USgpm are discharged to a large outside pond which stores reclaim brine, used to transport tails and cool the crystallizer circuit.

Brine is also produced by precipitation contacting the salt tails pile and salt deposited on the ground at the minesite. This brine, which can amount to 650 acre feet in a major rain, is directed to the reclaim brine pond. The volume of brine in the pond is increased by precipitation falling directly on it. As well the groundwater collected along with escaped brine that is collected in a series of drains and wells around the brine pond is returned to the pond.

Provincial regulations forbid the discharge of brine to surface water bodies or shallow groundwater. Because of its high salt content, the excess brine cannot spread on land. The potash industry in Saskatchewan must dispose of its excess brine in a manner which will not contaminate the environment.

When the potash industry was first established in Saskatchewan, it was thought that evaporation from the brine pond would be sufficient to keep the volume of brine in the brine ponds to acceptable limits. However, it was found that evaporation was about equal to the brine volumes produced by precipitation.

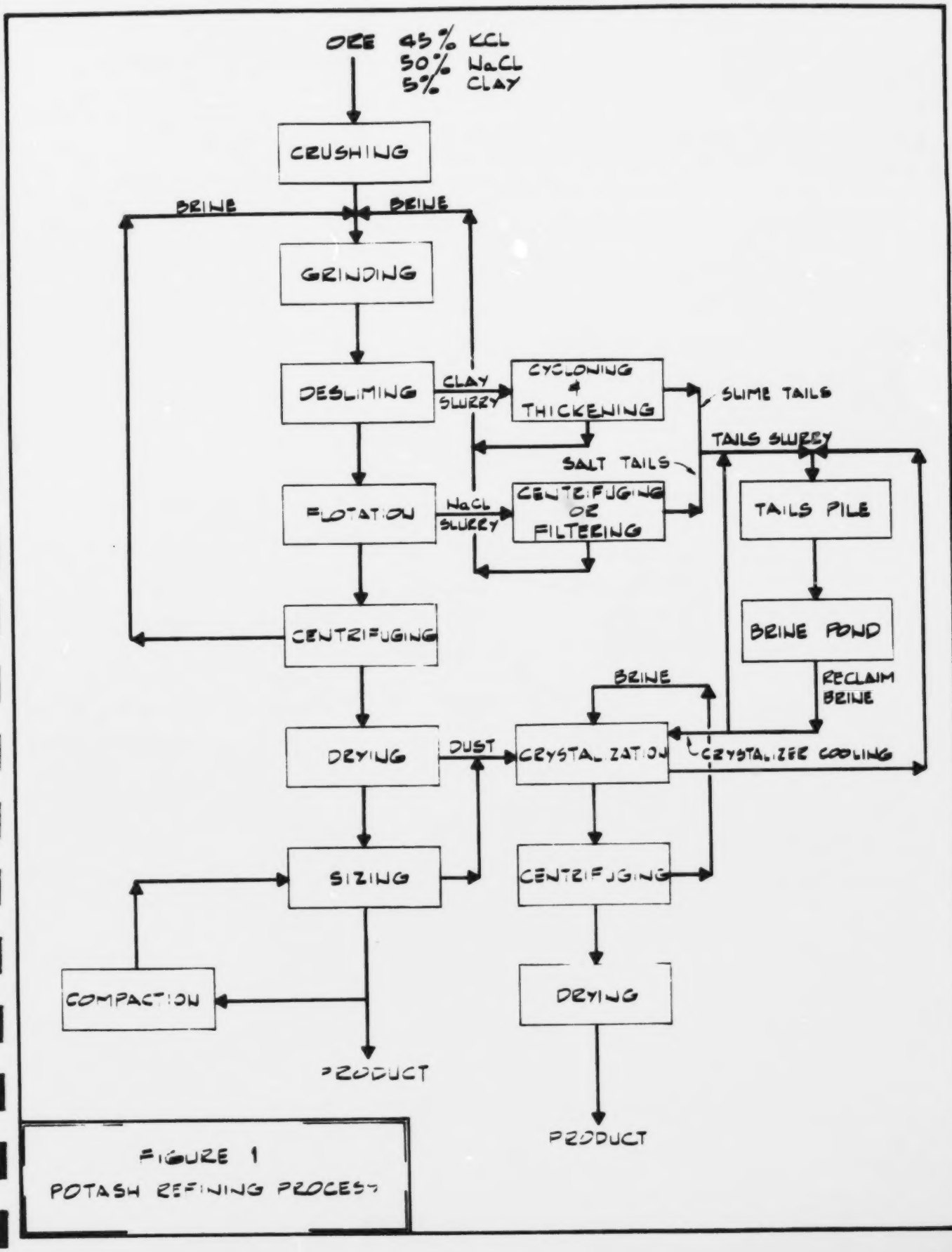
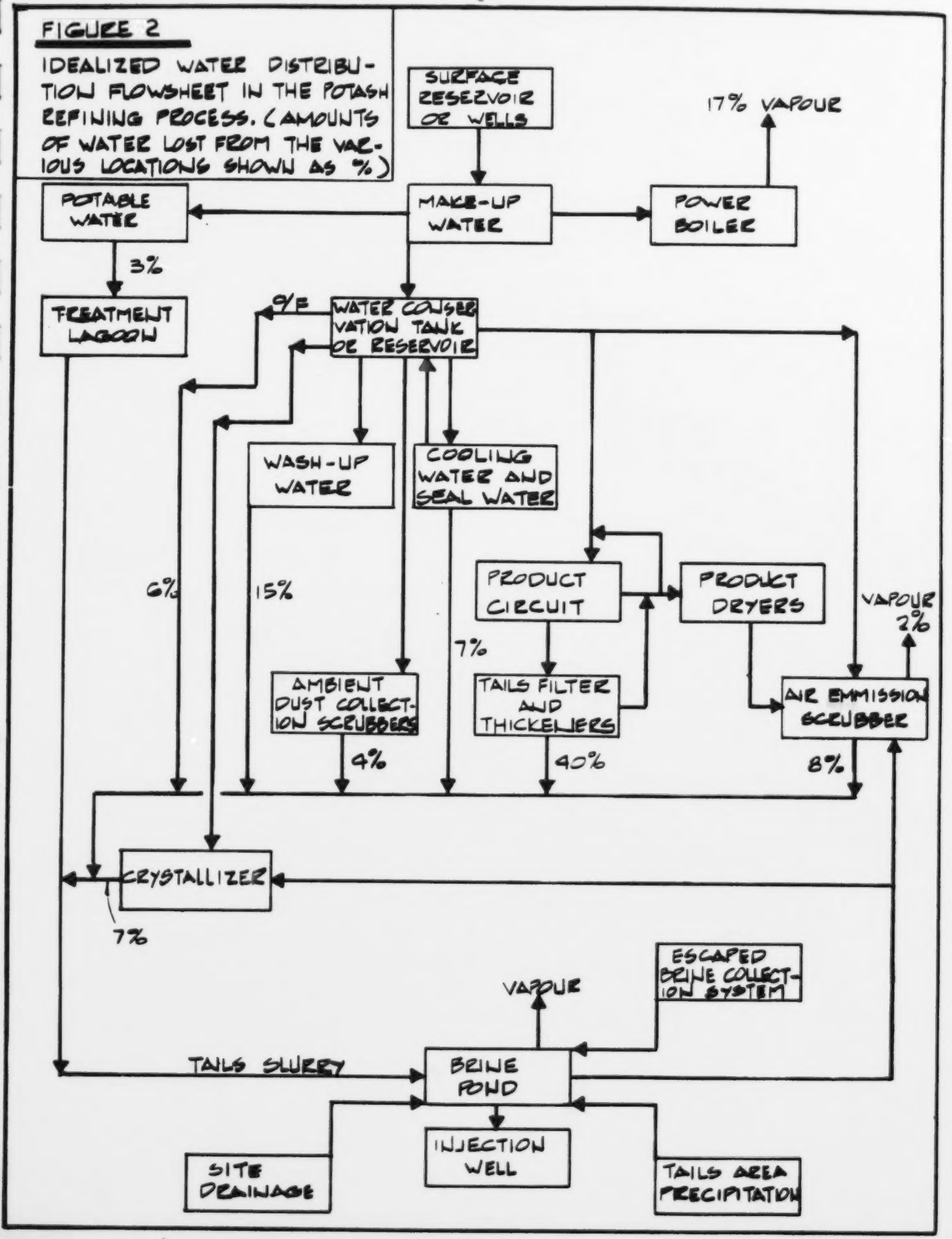


FIGURE 1
POTASH REFINING PROCESS

FIGURE 2

IDEALIZED WATER DISTRIBUTION FLOWSHEET IN THE POTASH REFINING PROCESS. (AMOUNTS OF WATER LOST FROM THE VARIOUS LOCATIONS SHOWN AS %)



The only other brine disposal options available for the industry in Saskatchewan are evaporators or deep well injection. Economics do not presently permit the use of evaporators, however, deep well injection is practical because within Saskatchewan various geological formations under the potash ore zones are capable of receiving the excess brine.

Only one of the 10 potash mines in Saskatchewan does not use deep injection for disposing of excess brine. PCS Mining uses seven wells, four of which are at its Rocanville Division. These wells, which cost about $1 M each to construct and up to $250 k/year to operate, constitute a significant portion of the costs of operating a potash mine.

This report summarizes PCS Mining's experience and knowledge of brine injection wells to provide information which may help to reduce these costs, and to determine how effective injection wells are in preventing environmental contamination.

METHODOLOGY

Visits were made to each of PCS Mining's Divisions to collect data from their files. Each mine extended full co-operation, allowing full access to the files and permission to copy any pertinent documents. Their co-operation is gratefully acknowledged.

LIMITATIONS TO THE STUDY

The study was limited by the lack of usable information in many aspects of the installation, maintenance and, particularly, the operation of the wells.

GENERAL OBSERVATIONS AND COMMENTS

The installation, operation and maintenance history for each well at the Divisions is summarized at the end of this report. For more details, reference should be made to the specific well file in the Environmental Affairs Section of PCS Mining at Suite 500, 122 - 1st Avenue South, Saskatoon, Saskatchewan, S7K 7G3.

DISPOSAL FORMATIONS IN SASKATCHEWAN

A potash brine disposal well requires that geological formations capable of assimilating the brine be present. The formation must be sufficiently permeable to absorb the desired volume of brine without requiring pumping pressures that are uneconomically high or which will lead to fracturing of the formation. A good disposal formation will be thick and extensive and will not communicate with any formation containing usable water. The discharge area for the formation's water should be located a great distance from the injection well and/or the rate of flow in the formation should be so slow that the injected brine will not emerge into the biosphere except in terms of geological time. By that time, and over that distance, the injected brine should be sufficiently diluted to be non-detectable. The injected brine should not react with formation fluids to reduce the assimilative capacity of the formation. It would be desirable for the receiving formation's water to be of a similar chemical composition to the injected brine so that there would not be concerns about salt contamination from injected brine even over a geological time span.

In the potash mining zone in Saskatchewan, there are about 4 430 ft. of sedimentary formation overlying the basement of precambrian crystalline rocks (Figure 3). In the stratigraphic section, there are a number of formations which could be used for injecting potash brine but the two best formations are the Winnipeg-Deadwood and the Interlake.

Of the two, the Winnipeg-Deadwood is a superior formation and all potash mines in Saskatchewan except those in the southeast corner of the province inject into this formation. This formation which is sandstone with a high permeability has been absorbing potash brine from five injection wells for almost twenty years without any evidence of pressure buildup. The discharge area for the Winnipeg Formation is near the shores of Lake Winnipeg and that of the Deadwood Formation appears to be located in the Black Hills of South Dakota. The formation water contains about 35% sodium chloride, and is generally similar to waste potash brine.

The Winnipeg-Deadwood Formation is in excess of 660 ft. thick in the Saskatoon area but is thinner or absent in southeastern Saskatchewan. In that area, potash mines use the highly fractured carbonates of the Interlake Formation which is about 330 ft. thick. The Interlake Formation, being composed of limestone and dolomites, is not as receptive to injected brine as the Winnipeg Deadwood. It is however, highly fractured and does absorb brine without excessive pressure buildup. It is believed that the majority of the brine is taken up by a few highly permeable fracture zones.

The Interlake Formation contains water with about 20% sodium chloride. Discharge from this formation appears to occur into the Manitoba lowland near Lake Winnipeg.

SOUTH EASTERN SASKATCHEWAN
SEDIMENTARY GEOLOGY
COMPOSITE
STRATIGRAPHIC SECTION

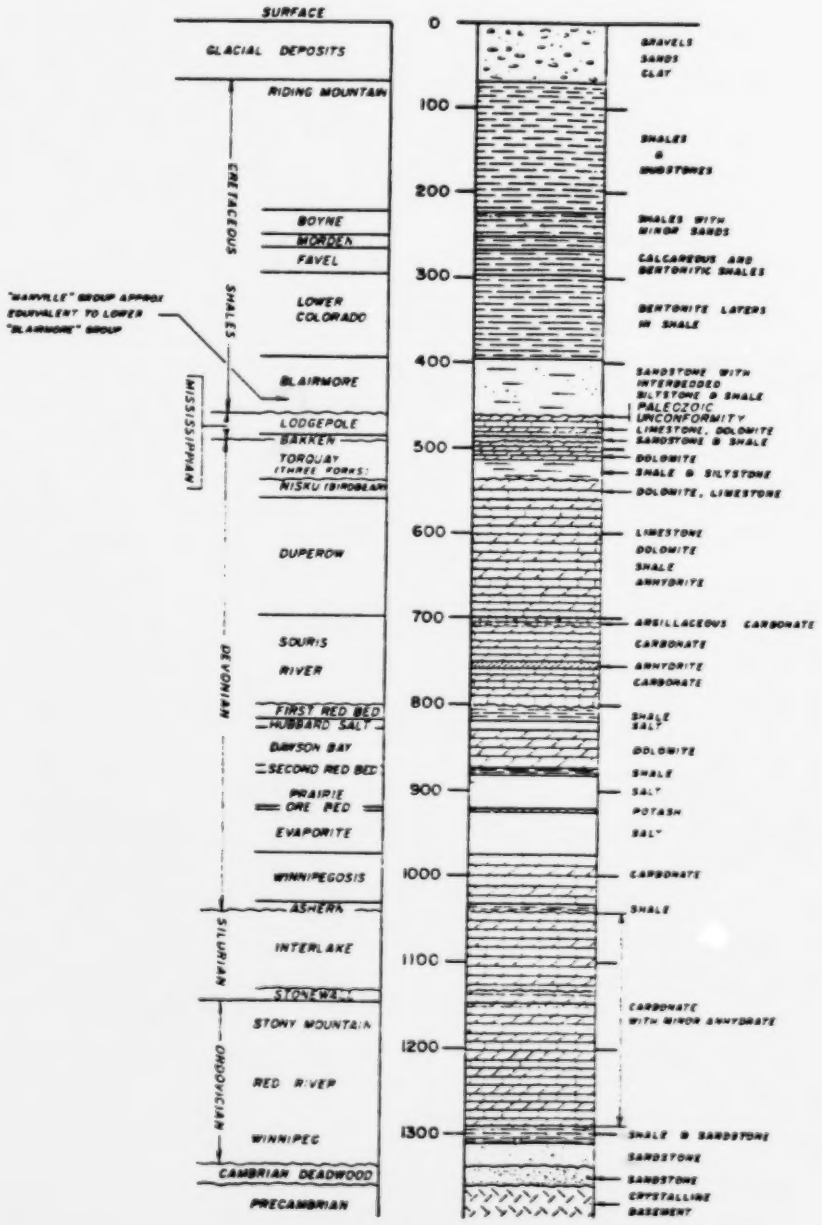


FIGURE 3

FIELD USE ONLY - DESCRIPTION OF REVISION

REVISIONS

No	DESCRIPTION	DATE	BY

SECTION
SCALE - 1/3000 DATE
DESIGNED BY:
DRAWN BY: L OLEKSUK SEPT /81
CHECKED BY: R J S SEPT /81
APPROVED BY

LOCATION:

PCS mining

TITLE:
SOUTH EASTERN SASKATCHEWAN
SEDIMENTARY
GEOLOGY-COMPOSITE
STRATIGRAPHIC
SECTION

M.E.E. No.
ACCT No.
PROJECT No.
DWG. No.
SH. of
REV

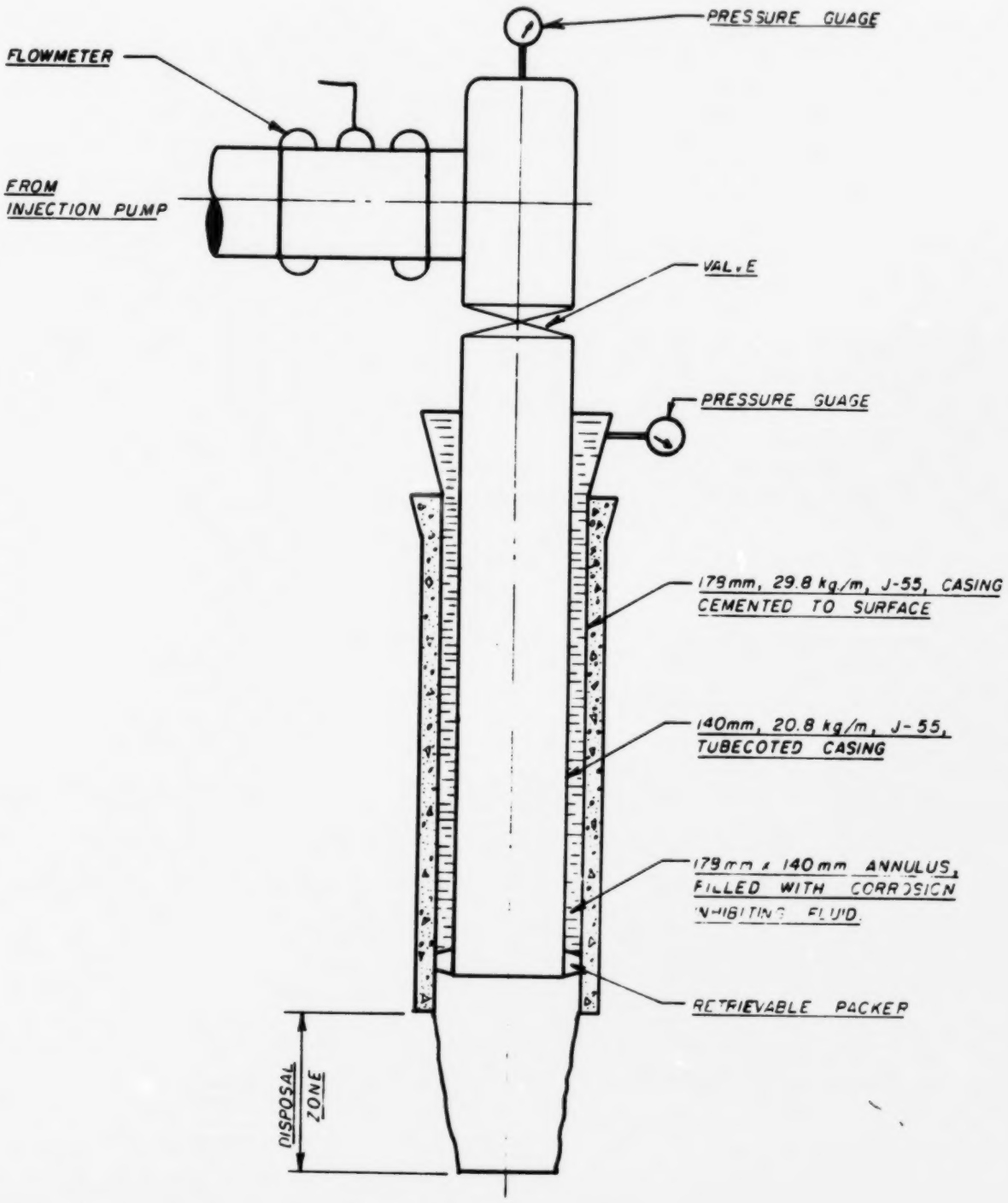
INJECTION WELL CONSTRUCTION

The outer part of PCS Mining's brine injection wells consists of an outer casing or pipe that is installed either from or near the disposal formation to surface (Fig. 4). This outer casing is cemented to the enclosing rock to seal off the various water bearing formations is poured from the bottom of the casing to the surface.

The actual injection pipe (tube or string) is then inserted down inside the casing into the disposal formation. A packer (seal) is placed down the hole to seal off the space between the two pipes. This space between the injection pipe and the inner casing is then filled with a corrosion inhibitor, generally diesel fuel, and is pressurized. If the diesel fuel leaks to surface or will not hold pressure, it indicates that the packer has failed or the injection pipe has developed a leak and repairs are necessary.

The actual injection is through slots or perforations in the injection pipe at appropriate depths. The Cory well and Rocanville No. 1 and No. 2 wells differ in that the outer casing is extended through the disposal formation and is perforated at various levels, with the injection pipe stopping at the top of the disposal formation. This method is questionable because the cementing of the casing may have an adverse effect on the ability of disposal formation to accept brine.

Rocanville wells No. 3 and No. 4, constructed in 1981 and 1985 respectively are completed as open holes. There is no casing or injection pipe through the disposal formation. This is now the recommended method as it allows the use of the entire disposal formation for injection and is also cheaper. Should anything happen, such as



"OPEN HOLE TYPE"

SECTION:		LOCATION:	TITLE: SALT WATER DISPOSAL WELL INTERLAKE OR WINNIPEG-DEADWOOD
SCALE: NONE	DATE		
DESIGNED BY:		Potash Corporation of Saskatchewan	
DRAWN BY:			
CHECKED BY:			
APPROVED BY:			

M.C.C. No.	
ACC'T No.	
PROJECT No	
DWG. No	
SH. of	REV.

plugging or caving to the open hole, the ability to accept brine can be restored by various well established methods employed in oil fields.

After completion of the well, cathodic protection is then installed to inhibit corrosion of the well. Rocanville wells No. 3 and No. 4 do not yet have this protection but it is planned. No information was available on the details of any protection provided for Rocanville No. 1 and No. 2 wells.

It should be noted that some of the information concerning the installation of the early wells could not be located. All of the various tests and reports generated during the installation should be retained by the Divisions for the life of the well.

OPERATIONS

With the exception of the Allan Division well, readily usable data on the operation of the wells were not available. In most instances, the raw data is available, however, time did not permit us to tabulate and summar- ize the raw data to illustrate the operational history of each well. Generally the capacity of wells discharging into the Winnipeg-Deadwood Formation is 64-138 $ft.^3$/min. while wells discharging into the Interlake Formation is 32-85 $ft.^3$/min.

Allan Division has constructed charts on an annual basis since the well was placed into operation. The graphs show flow rate, well head pressure, annulus pressure and brine temperature for each twelve month period. These types of data would be valuable for all waste brine injection wells.

Because of the lack of readily usable data, the ability to comment on the performance of the wells is limited.

The Saskatchewan Department of Energy and Mines requires an annual formation pressure fall-off test of each well. An examination of the results of these tests over the years shows that the disposal formation static pressure is not increasing to any significant degree. This indicates that the formation is accepting the injection satisfac- torily and is dissipating the brine within the formation.

MAINTENANCE

This survey was confined to the brine disposal well. No effort was made to document the problems associated with equipment such as pumps, lines, and electrics.

The major problems have been the failure of the packer, leaks developing in the injection pipe and decreases in rate of flow accepted by the disposal formation. Packer failures or pipe leaks require the removal of the injection string and replacement of the failed part. These are generally not preventable as failure cannot be predicted. Rehabilitation is easier if packers are designed to be easily removable. Packers should be designed to be suitable for the intended service.

For reasons not readily understood, the rate of flow into the formation generally decreases with time. It may be that the formation is salting up due to crystallization. The usual repair procedures is to perforate additional lengths of the injection pipe. This is a relatively quick solution that does not require the removal of the injection string from the hole.

Obstructions in the well may be reduced if the well is shutdown and allowed to drain completely instead of being drained back to the sump. This will reduce inward and upward pressure which could move packers upward or bring debris into the well.

Some of the mines have attempted to improve performance by acidizing the well with HCl. It should be noted that Rocanville is the only PCS Mining Division disposing into a carbonate formation (Interlake) and the use of HCl acid at the other mines is questionable as they dispose into sandstone (Deadwood Formation) which will not be affected by HCl.

OTHER OBSERVATIONS

Improving Cost Effectiveness of Wells

Consideration has been given to possible gravity feed at Allan. However, it appears that a low pressure pump would still be required to ensure an adequate flow. As documented in the file, the Lanigan well plugged with salt due to gravity feed due to back syphoning when the pumps were shut off for a period of time.

Allan Division's staff reports that consideration is being given to adding fresh water to the brine to improve disposal rates. Very little data is available to support this technique and only actual experience or research will be able to determine its effectiveness. Cory Division adds 3-4 $ft.^3$/min. to prevent the pumps from crystallizing with salt.

Most potash mines do not continuously need the full capacity of the injection wells. Therefore, there are periods throughout the year when the wells are shutdown. The "salting-up" of wells appears to be associated with shutdown and it is advisable to operate the wells continuously at a lower rate rather than shutdown and promote salting-up. On the other hand, there must be a capacity to rapidly inject the large amounts of brine which are formed by precipitation falling on the brine and tails storage area. A solution could be to operate each well with two pumps, a low pressure pump which would be operated continuously to provide a rate of flow sufficient to prevent "salting-up", and a high pressure pump which would be used when large volume of brine requires rapid disposal.

Locating Wells

To date, the refinery staff have chosen the site for the disposal well on the basis on convenience to the site. When an additional well is to be installed, attention must be given to the possibility of wells interfering with each other thus could reduce each of their assimilation capaci- ties. An qualified reservoir engineer, if involved in the site selection, could calculate the optimum separation so that the wells do not interfere with each other. It is reported, though not documented, that the Rocanville wells interfere with each other.

Injection wells should not be located in areas where faults or other geological anomalies could allow the injected brine to move towards the surface and threaten mine safety or contaminate shallower groundwater. Seismic surveys could be utilized when selecting well sites, to ensure these anomalies are absent.

Impact of Brine Injection on the Disposal Formations

There has been concern expressed regarding the quantity of brine which can ultimately be injected into the disposal formations and what happens to this brine. The Saskatchewan Department of Energy and Mines consider these disposal formations to be similar to huge lakes and that the rela- tively "small" quantity added from injection is absorbed and distributed throughout the formation with negligible effect.

It would be possible to at least estimate the ultimate assimilative capacity and effects on the disposal formation, without involving the huge expense of an extensive deep drilling program, if there are sufficient drill stem test data available from existing wells. An qualified reservoir engineer should be able to determine if the data available will permit this assessment.

Since there is a general lack of good geological data on the disposal zones, the zones have not been properly characterized. The ava'lable knowledge would be greatly enhanced if the disposal zones were cored in any new wells. The value of the data collected would justify the relatively small additional expenditure.

USE OF INJECTION WELLS BY OTHER INDUSTRIES

A brief survey was made of injection wells used by other industries to determine if different injection techniques outside the potash industry could be profitably adopted by PCS Mining. A number of experts in the field were consulted and an inspection visit was made to a location where a new hole was being drilled.

There is increased interest by industry in injection wells, particularly as a vehicle for disposing of toxic wastes. Concern has arisen in the United States about the safety of the use of injection wells for this purpose. The Chemical Manufacturer's Association has recently formed a committee to study and report on the design, operation, and environmental impact of injection wells.

Generally, the injection wells used outside the potash industry employ techniques similar to that of the potash industry. The most important factor for a successful injection well is favorable characteristics of the receiving formation. The best construction, operation, and maintenance techniques for a particular injection well will be a function of the characteristics of the receiving formation. Since the Winnipeg-Deadwood and Interlake Formations are unique, it is felt that efforts should be made to refine techniques already in use in Saskatchewan rather than to attempt to transfer technology which was successfully used elsewhere for different formations and for injecting different substances.

SUMMARY

The objectives of the study were only partially attained because data were not available. More data will have to be collected and better records maintained of the construction, operation and maintenance phase of brine injection wells if case histories are to be used to understand the properties of brine injection wells.

The assimilative capacity of the disposal formation appears to be the major factor affecting the performance of a well. Open hole construction yields the most cost effective well. The value of acidization as a well rehabilitization technique is questionable in wells discharging into non-calcareous formation.

The Winnipeg-Deadwood and Interlake Formations appear to be accepting the brine with no short or long term effects. Wells could probably be made more effective if more attention was given to the geology when locating them and use was made of specialists to interpret this geological data.

APPENDIX A

HISTORY OF THE INJECTION WELL AT ALLAN DIVISION

WELL NAME: APM Allan Disposal D13-22-34-1

INSTALLATION

The disposal (brine injection) well was completed on July 12, 1971, and the first injection occurred in the same month. Problems during the drilling of the well resulted in the well having a "dog-leg".

At the time of construction, the well consisted of an outer 7 in. casing cemented from surface to 4 690 ft., and an inner 5-1/2 in. casing (the actual injection pipe or tubing) from surface to 5 505 ft. The 5-1/2 in. injection pipe was epoxy lined and slotted from 4 691 ft. to 4 779 ft. and 4 991 ft. to 5 505 ft. through which the brine is injected to the Upper and Lower Deadwood (sandstone) Formations.

A retrievable packer was set at 4 604 ft. to seat the annulus (space) between the 7 in. and 5-1/2 in. casings or pipes. This annulus was then filled with diesel fuel to surface.

The injection of brine commenced at a flow rate of around 300 USgpm and by October 1971, the well was operating at around 700 USgpm.

The well is equipped with Cathodic Protection.

Water is added to the sump, not to the injection line, in order to keep the sump screens from salting up.

OPERATION AND MAINTENANCE

On March 28, 1972, a leak of diesel fuel was noted at the well site. Subsequent investigation showed that a leak had developed between the 5-1/2 in. injection pipe and the 7 in. casing. Cavern Engineering was contracted to supervise repairs. Considerable difficulties were experienced in repairing the well.

The 5-1/2 in. injection pipe was pulled from the hole and it was discovered that this pipe or casing had collapsed in two places at around 3 860 ft. from surface. The collapse was attributed to a failed packer which allowed high pressures to develop in the annulus between the outer casing and the injection pipe. When attempts were made to retrieve the failed packer, the injection pipe broke at about the 4 560 foot level and attempts to retrieve the remaining 945 ft. of pipe and the packer failed. The failed section of injection pipe was replaced and a new packer was installed at the base of the pipe at 4 523 ft. The repaired injection pipe could not be connected to the segment which could not be pulled from the hole. As a result, the 5-1/2 in. injection pipe is broken from 4 523 to 4 560 ft.

The injection well operated satisfactorily absorbing at a rate of 500-700 USgpm, until 1977/78. At that time, a new brine pond was built and, since brine injection was not needed, the well was shutdown for several months. When injection resumed, the well was found to be capable of absorbing initially only 135 USgpm and ultimately only 200-300 USgpm. The poor performance was attributed to salting-up during the shutdown. Backflushing of the well was attempted to clean the injection pipe but the equipment was unable to penetrate beyond the break at 4 560 ft. and backflushing through the whole disposal section could not be accomplished. The decision was then made to perforate a new upper portion of the disposal horizon. This was carried on January 26, 1981.

The perforation pattern was two holes per vertical foot from 4 700-4 780 ft. and 5 000-5 200 ft. Diameter of perforation estimated at 3/8 in.

Since 1981, the flow rate has remained at the 800-900 US gpm rate.

COMMENTS

The annual formation pressure fall-off tests do not indicate any significant build-up in formation pressure.

Additional thickness of the disposal zones can be perforated in future to maintain an "acceptable" 500-700 USgpm rate of disposal for this well.

The "dog leg" combined with two packers and broken pipe makes well rehabilitation difficult. It is usually impossible for equipment to enter the bottom portion of the injection pipe below the break.

To prevent future failure, a careful well start-up and shutdown procedure has been instituted to avoid shocking the injection pipe and the packer. Whenever the level of suspended solids in the brine exceed 10 ppm, the well is shutdown.

APPENDIX B

HISTORY OF THE INJECTIONS WELL AT CORY DIVISION

WELL NAME: Duval Saskatoon SWD 8-13-36-7

INSTALLATION

The well was completed on November 29, 1970, with first injection occurring in April 1971. A review of the records indicates that the well was completed without significant difficulty although there was some initial concern regarding hole deviation above 3 000 ft. and a problem with the cementing of the outer casing.

The well consists of an outer 9-7/8 in. outer casing cemented from surface to 5 517 ft. and an inner 5-1/2 in. injection pipe from surface to 4 159 ft. The 5-1/2 in. injection pipe is not lined, but is a heavier grade (N80L, 20 lbs per foot) pipe than at the other Divisions. The packer between the outer casing and injection pipe was set at 4 182 ft. and the space (annulus) between filled with diesel fuel.

The Cory Division well differs in that it injects through the outside (long string) casing which is cemented from surface to the bottom of the well. This casing was perforated for a total of 270 ft. between 4 645 and 5 505 ft., at intervals of one shot per foot; diameter of perforations was 0.58 in. The formations perforated were the Winnipeg, between 4 645 and 4 720 ft., and the Middle and Lower Deadwood between 5 054 ft. and 5 505 ft.

During the installation of the well, the cement bond log indicated poor bonding above the salt at 3 201-3 301 ft. Cement was squeezed into this area to correct this problem.

OPERATIONS AND MAINTENANCE

From 1971 to 1977, the well is reported to have apparently operated satisfactorily. The initial tests in November, 1970 indicated that the well could accept about 400 USgpm. Over the years, the well has been operated at a pressure of about 870 psi which resulted in a assimilative capacity of about 800 USgpm.

In October, 1978, it was discovered that the annulus was leaking diesel fuel which indicated failure of the injection string. In October, 1979, repairs were carried out to the well. The cause was found to be a leak in the cemented outer casing at 3 201 ft. At the same time, additional perforating of the outer casing was carried out to improve injection performance.

By June 1985, the well's assimilative capacity had deteriorated to where a pressure of 960 psi was required to dispose of 560 USgpm. As usual, in these cases, the well's performance was scheduled to be improved by re-perforating in the original injection zone. However, an obstruction was encountered about 215 ft. above the bottom of the hole. Since the perforating gun could not pass the obstruction, four sections, each 23 ft. long above the obstruction in the section of the well from 4 662-5 236 ft., were perforated. A new packer was installed above the new injection zone.

Fifteen hours after perforating, the well was absorbing 800 USgpm at 920 psi. The well's productivity index after perforating was 1.055 USgpm/psi, compared to 0.5045 USgpm/psi before rehabilitation.

The cause of the obstruction which reduced well performance is not known. It is considered unlikely that sand had filled the well to the point of obstruction since no other well in the Deadwood Formation has ever become obstructed with sand. A possible cause for the obstruction is the drawing up of the old packer by the pressure produced when the well was drained. During draining, the practice has been to bleed the well back to the well sump. This causes the well to flow upward and could draw the packer upward or debris into the well.

COMMENTS

Dilution water (20-24 gpm) is added to keep the pump from crystallizing with salt.

Formation pressure fall-off tests do not indicate any significant increase in formation pressure.

Cathodic protection has been installed.

APPENDIX C

HISTORY OF THE INJECTION WELL AT LANIGAN DIVISION

WELL NAME: Alwinsal Lanigan 1-20-33-23

INSTALLATION

The injection well was completed on September 10, 1975. The well consists of an outer casing from 0 to 4 615 ft., and an inner, tube coated, 5-1/2 in. injection pipe from 0 to below 4 565 ft. A 600 ft. length of 4-1/2 in. slotted liner (48-0.030" slots per ft.) was hung from a liner hanger type packer at 4 565 ft. The injection is through this liner into the Upper, Middle and Lower Deadwood Formations from 4 651 ft. to bottom of the hole (5 212 ft.).

A review of the available records does not indicate any significant incidents during the drilling and installation of the well.

Cathodic protection was installed in 1977.

OPERATION AND MAINTENANCE

Although the well was completed in September, 1975, the first injection did not occur until February, 1976. Details are lacking but apparently the original plan was to run the well by gravity feed. This plan was abandoned and pumps were installed. The initial rate was 450 USgpm at 350 psi.

The well functioned satisfactorily until 1980 when a blockage developed. On November 29, 1980, an attempt was made to clear the blockage by pressurizing and pumping, but without success as the 3 in. valve on the well head split.

On April 13-16, 1981, the injection string was pulled and it was found that the string had plugged with salt in the pipe at around 500 ft. in the pipe. The obstruction was cleared and the injection string placed back in the well.

The probable cause of the blockage is considered to be salt build-up from intermittent injection to that time, and syphoning of brine down the pipe as there was not shut-off valve on the discharge end of the line.

On April 28, 1982, the well was perforated to increase capacity. The perforating was done over four relatively short intervals (10-20 ft.) from 4 900 to 5 160 ft. The present capacity is now stated to be 850 USgpm at 350 psi.

COMMENTS

The well appears to be operating satisfactorily at this time. With mine expansion there is a requirement to dispose of additional brine. Plans have been made to increase the well capacity to 1 200 USgpm at 835 psi.

There is no opportunity to dilute the brine since there is no fresh water line at the present pump location. However, relocation of the brine injection pumps to the reclaim brine return pumphouse where there will be fresh water is planned.

The injection well is used mostly during the period of March to November.

Formation pressure fall-off tests carried out in 1977, 1979 and 1981 indicated no significant increase in the formation pressure. No fall-off tests have been carried out since 1981. This is primarily due to operational difficulties such as long shutdowns. A pressure test is scheduled for this year.

APPENDIX D

HISTORY OF INJECTION WELLS AT ROCANVILLE DIVISION

BRINE INJECTION WELL NO. 1

WELL NAME: Sylvite Ste. Marthe 1-14-17-30

BRINE INJECTION WELL NO. 2

WELL NAME: Sylvite Ste. Marthe 3-20-17-30

Both of these wells were completed in 1971 in the same manner and placed in operation in early 1972. The wells consist of a 7 in. casing cemented to surface and an inner 4-1/2 in. (No. 1) or 5 in. (No. 2) injection string. The inner string stops approximately 1 000 ft. from the bottom of the hole, whereas the outer casing carries on down to the bottom of the hole. This outer casing is perforated for disposal into the Interlake (dolomite) Formation at around 3 600-3 800 ft.

These two wells differ from the other PCS Mining wells in that they are gravel packed and have a stainless steel screen in the Winnipeg Sandstone Formation as well as being perforated in the Interlake Formation. The injection strings are plastic lined. The annulus between the casings is filled with a mixture of 25% methanol and 75% inhibited water.

OPERATIONS AND MAINTENANCE

Brine Injection Well No.1

In June 1981, the well was re-perforated in two sections at four shots per ft. from 3 822-3 834 ft. and 3 768-3 814 ft. to improve disposal performance. The well was acidized at the same time and the performance was reported to have improved to 430 USgpm at 400 psi.

In August, 1984, the well was examined for an annulus leak. The injection string was pulled, the leak located in the first joint near surface, and the packer replaced and set in the hole at 3 554 ft..

The well operated for two days at a normal rate and than decreased markedly. It was suspected that either the new packer or the old packer left in the hole was malfunctioning.

In November, 1984, the well was re-worked and considerable amounts of shale and lining particles were discovered to be interfering with flow. These were removed and the wells performance is now in the 225-265 USgpm range.

Brine Injection Well No. 2

In June, 1981, the well was re-perforated from 3 744-3 890 ft. at 4 shots per post. The well was acidized at this time. There is no record of any improvement.

In June, 1984, the well was worked over to improve its performance which had deteriorated during 1983, and to repair a suspected annulus leak. As in well No. 1, the leak was found near the top of the injection string. At this time, the 5 in. injection string was changed over to 5-1/2 in. string to increase performance. A new packer was set at 3 115 ft., which is the end of the new 5-1/2 in. string. This well now has a capability of about 600 USgpm.

BRINE INJECTION WELL NO. 3

WELL NAME: PCS Rocanville 12-22-17-30W1

BRINE INJECTION WELL NO. 4

WELL NAME: PCS Rocanville 6-23-17-30

Wells No. 3 and No. 4 were completed on November 19, 1981, and February 3, 1985 respectively. Both wells were completed with a similar configuration. These wells differ from earlier disposal wells at this mine in that they are completed as open hole throughout the disposal formation (Interlake carbonate). That is, they have no injection pipe through the disposal formation.

Well No. 3 consists of an outer 7 in. (178 mm.) casing cemented from 3 543 ft. to surface, and an inner lined injection string from surface to 3 616 ft., with the packer set at 3 543 ft. The 6-1/4 in. open hole extends from the injection string to 3 937 ft. in the Interlake Formation.

Well No. 4 consists of similar outer casing cemented from surface to 3 563 ft. and inner casing or injection string from surface to 3 540 ft., with the packer set at 3 541 ft. The 6-1/4 in. open hole extends from 3 563 ft. to 3 970 ft. in the Interlake carbonate disposal formation.

Neither well is equipped for cathodic protection or fresh water dilution.

OPERATION AND MAINTENANCE

The No. 3 well was installed to increase injection capacity. The No. 4 well was installed to dispose of water from a mine leak which occurred at the end of 1984. Both wells are functioning satisfactorily with No. 3 receiving about 620 USgpm and No. 4 about 290 USgpm.

In April 1982, the annulus of No. 3 well developed a leak due to packer failure. The packer which was not designed for positive displacement pumps was pulled, and replaced with a retrievable model designed for the intended service. No. 4 is scheduled to have the sheaves on the injection pump replaced which is expected to increase its capacity to about 500 USgpm.